Co-firing in coal power plants and its impact on biomass feedstock availability

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Legislation Affecting Biomass Production in the U.S.

Federal legislation to address greenhouse gas emissions in the United States

- 2005 Energy Bill
  - Renewable Fuel Standard (RFS)
  - Increasing amount of cellulosic biofuel in gasoline
- Proposals for a U.S. cap-and-trade system
  - American Clean Energy and Security Act of 2009
  - American Power Act of 2010

State legislation

- Renewable Portfolio Standards (RPS) in 29 U.S. states
  - E.g., 25% of renewable energy in Minnesota by 2025
  - Biomass as part of the renewable options in all states

Biomass Demand and Agriculture

Two demand sources for biomass:

1. Biofuel plants (corn and cellulosic)
2. Electric power plants
   - Dedicated power plants
   - Co-firing power plants

Research questions:

- What is the potential for spatial competition among biomass users?
- What is the effect of co-firing existing coal power plants with biomass on agriculture?

Influence of federal and state policy on lignocellulosic biomass such as agricultural residues, energy crops, and forest residues

Biomass Co-firing

Advantage of co-firing

- (Almost) ready to use for co-firing
- Lower greenhouse gas emissions when compared to biofuels
- Existing infrastructure and location

Co-firing coal power plants

- Relatively easy retrofitting of existing coal-fired power plants
- Small and low cost modification to existing power plants

Biomass feedstock:

- Crop residues
- Energy crop
- Forest residues

Competition of power plants for limited biomass resources

Power Plant Location

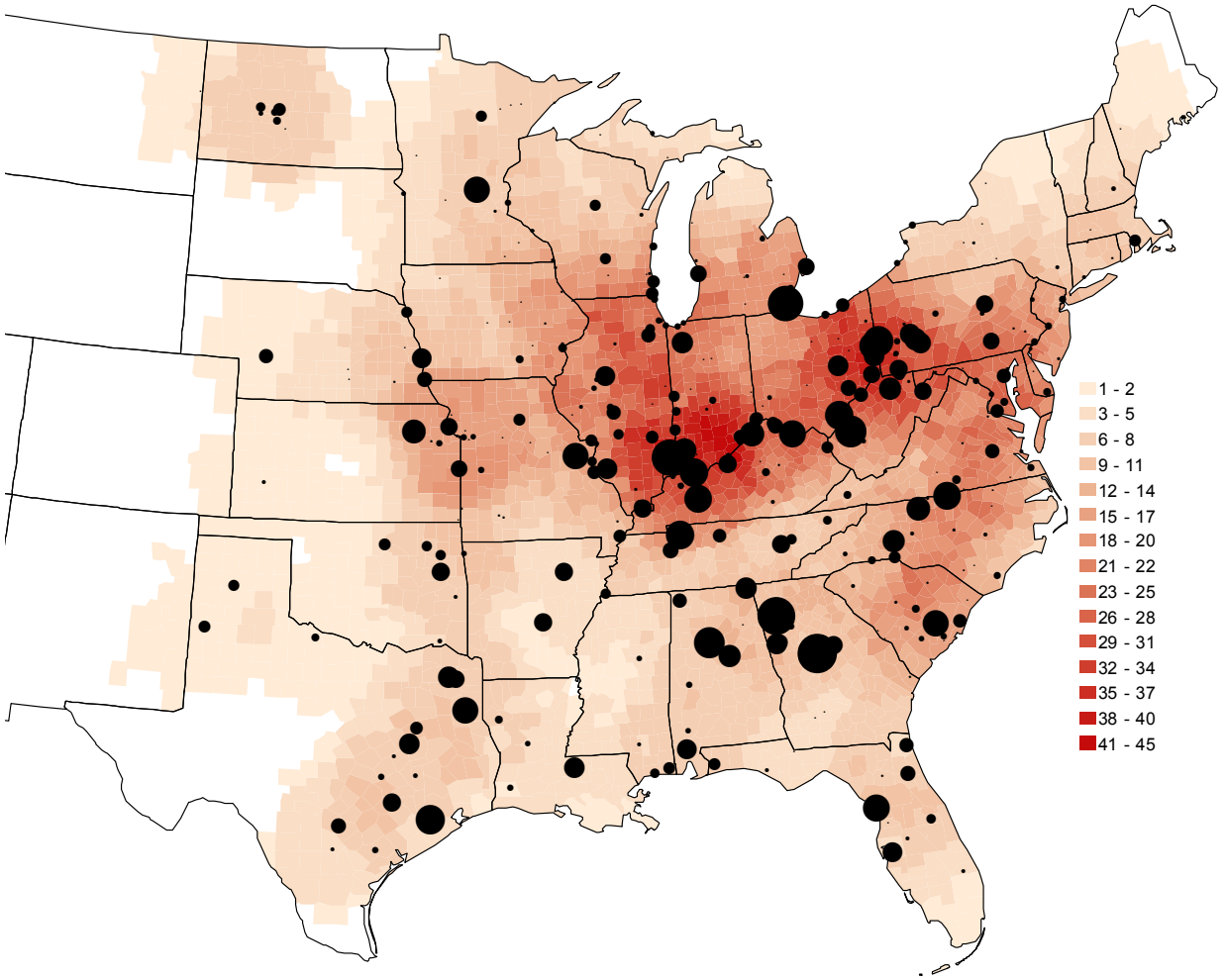


Figure : Number of power plants within 200 km of county's centroid

Literature Review

Energy Information Administration (EIA): 25% RFS (sales) and 25% RPS by 2025

- Rise of biomass consumption from 30 million tons to 571 million tons (2007-2030)
- Price increase of biomass from $30 to $88 per ton

Biomass analysis in the context of lignocellulosic ethanol production or co-firing

- Biomass availability for ethanol (Mabee et al. 2011)
- Transportation cost analysis for parts of Michigan (Egbendewe-Mondzozo et al., 2011) or Spain (Panichelli and Gnansounou, 2008)
- Co-firing and transportation in Illinois (Khanna et al., 2011)

Co-firing forest residue

Model Components

Agricultural sector

- Field crops: corn, soybean, and wheat
- Energy crop: switchgrass
- County-level allocation of cropland given prices

Electricity sector

- 398 Coal-fired power plants

Transportation cost

- Availability of all biomass at the centroid of the county
- Cheapest biomass based on distance and available quantity $\Rightarrow$ Lowest marginal cost

Forest sector

Agricultural Sector

Calibration of demand and net revenue functions:

- Corn, soybeans, and wheat
- Four demand sectors: food/domestic, feed, exports, and biofuel
- Cost by region from the USDA/ERS Commodity Costs and Returns

Expectations are rational in the sense that:

- Price taking behavior of all landowners
- Area allocation matches expectations about aggregate production and prices

Profit maximization for field crops

$$B_i^f(a) = \sum_j p_j \left(a_{ij}^f + a_{ij}^b\right) y_{ij} + \alpha_{ij} \left(a_{ij}^f + a_{ij}^b\right) + \frac{1}{2}\beta_{ij} \left(a_{ij}^f + a_{ij}^b\right)^2$$

Profit maximization for biomass crops

$$B^b(a) = p_{bm} \sum \delta_{ij} y_{ij} a_{ij}^b - \eta_{ij} a_{ij}^b$$

Electricity Sector

Data on 398 coal fired power plants (2010 Energy Information Administration)

- Type of coal (i.e., anthracite, bituminous, lignite, sub-bituminous)
- Sectors: electric utilities, independent power producers (IPP), and independent power producers with combined heat and power (IPP CHP)
- All North American Electric Reliability Corporation (NERC) regions except Western part of the country (i.e., WECC)

Assumptions:

- No investment decision of co-firing
- Unaffected heat input of the power plant
- Uniform boiler efficiency of 88% and 8000h of yearly operation

Scenarios

Table : Summary of key scenario parameters

Scenario	RPS	p_{bm}	Switchgrass Cost
RPS 15: Low Incentive	15%	\$3	High
RPS 15: High Incentive	15%	\$4	Low
RPS 25: Low Incentive	25%	\$3	High
RPS 25: High Incentive	25%	\$4	Low

Simulation Procedure

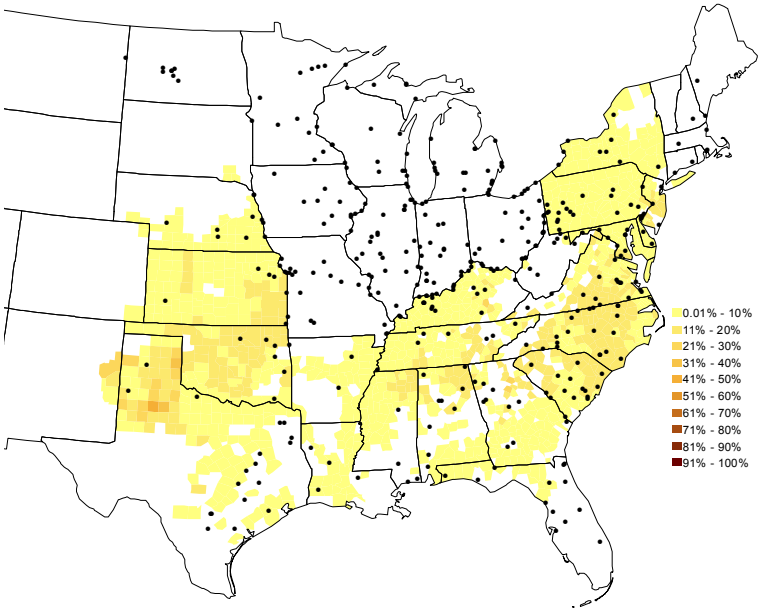
Exogenous variables:

- Price of biomass
- RPS requirement

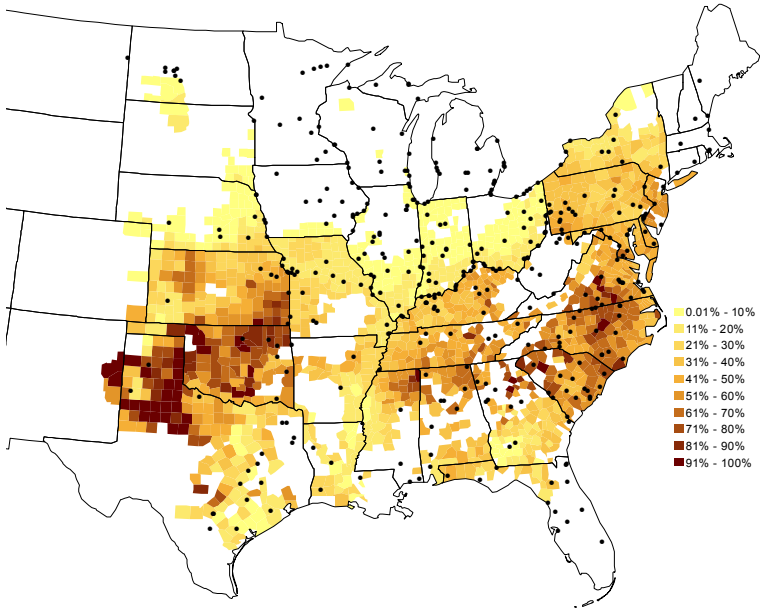
Simulation steps:

1. Set p_{bm} and RPS
2. Land allocation by the farmer and production of agricultural residues and/or switchgrass
3. Demand of coal-fired powerplants to individual counties based on transportation cost and biomass price
4. Calculate excess supply and demand of biomass

Share of Cropland in Switchgrass



(a) Low incentive



(b) High incentive

RPS 15: Low Incentive

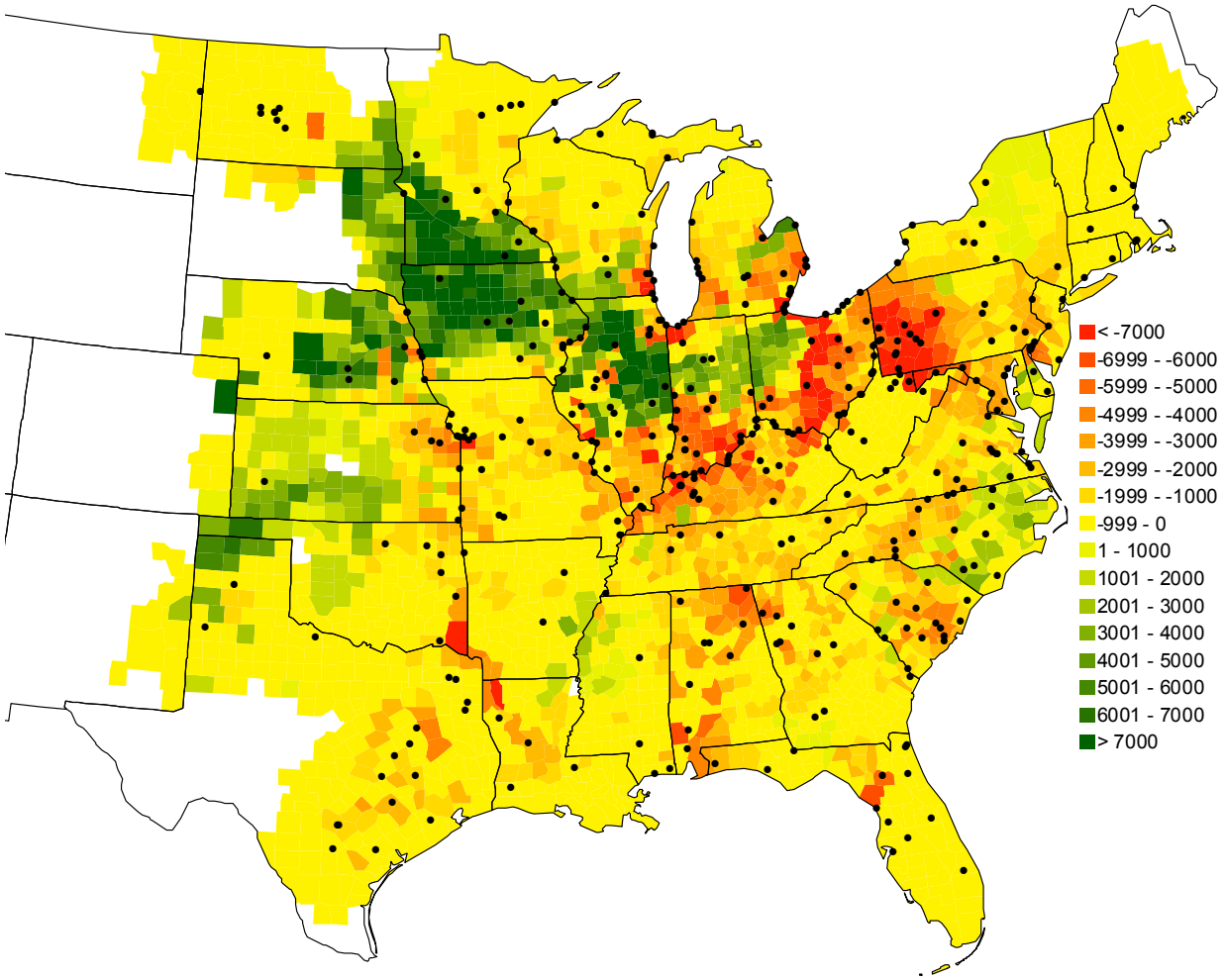


Figure : RPS = 15%, p_{bm} = \$3, High Switchgrass Production Cost

RPS 15: High Incentive

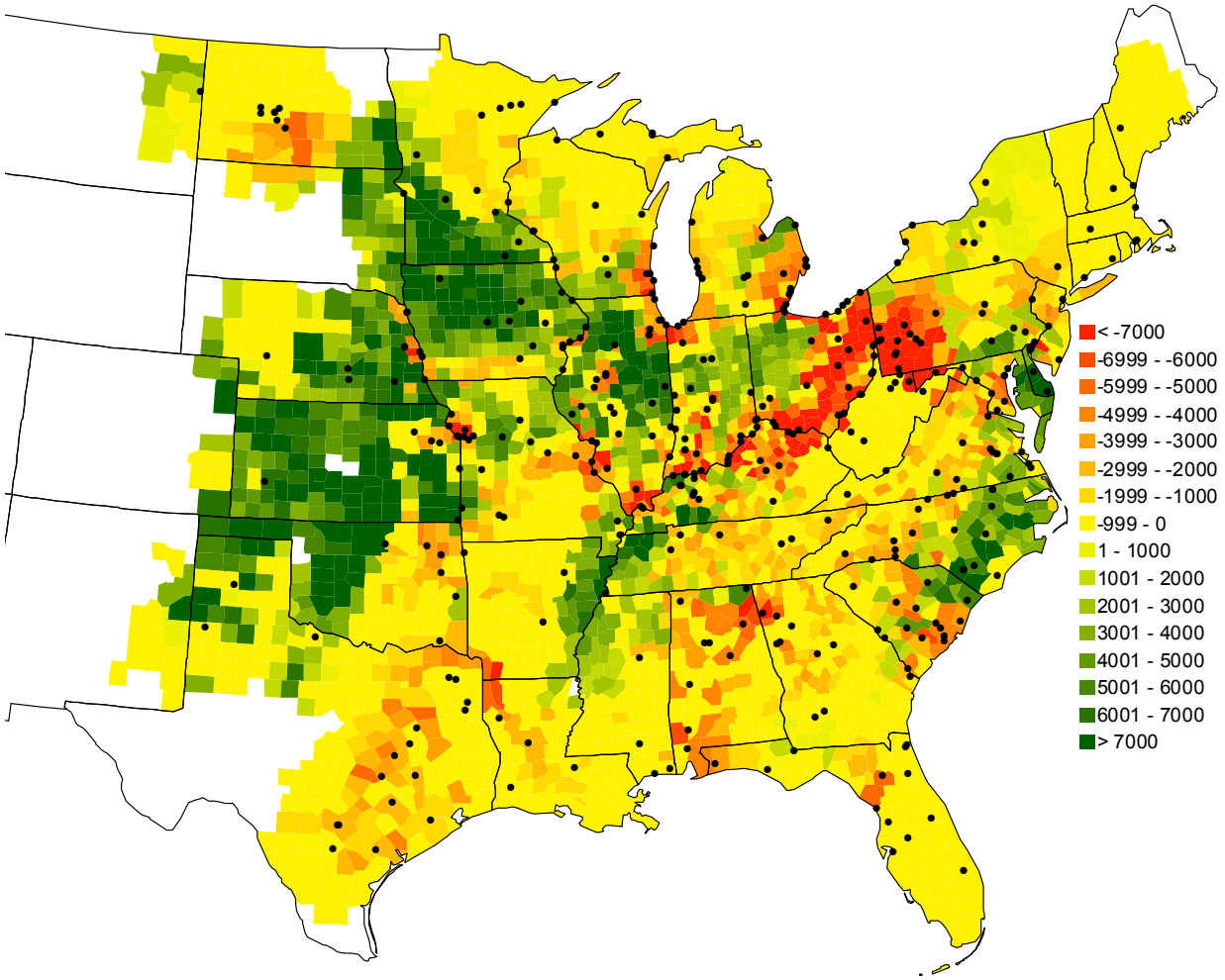
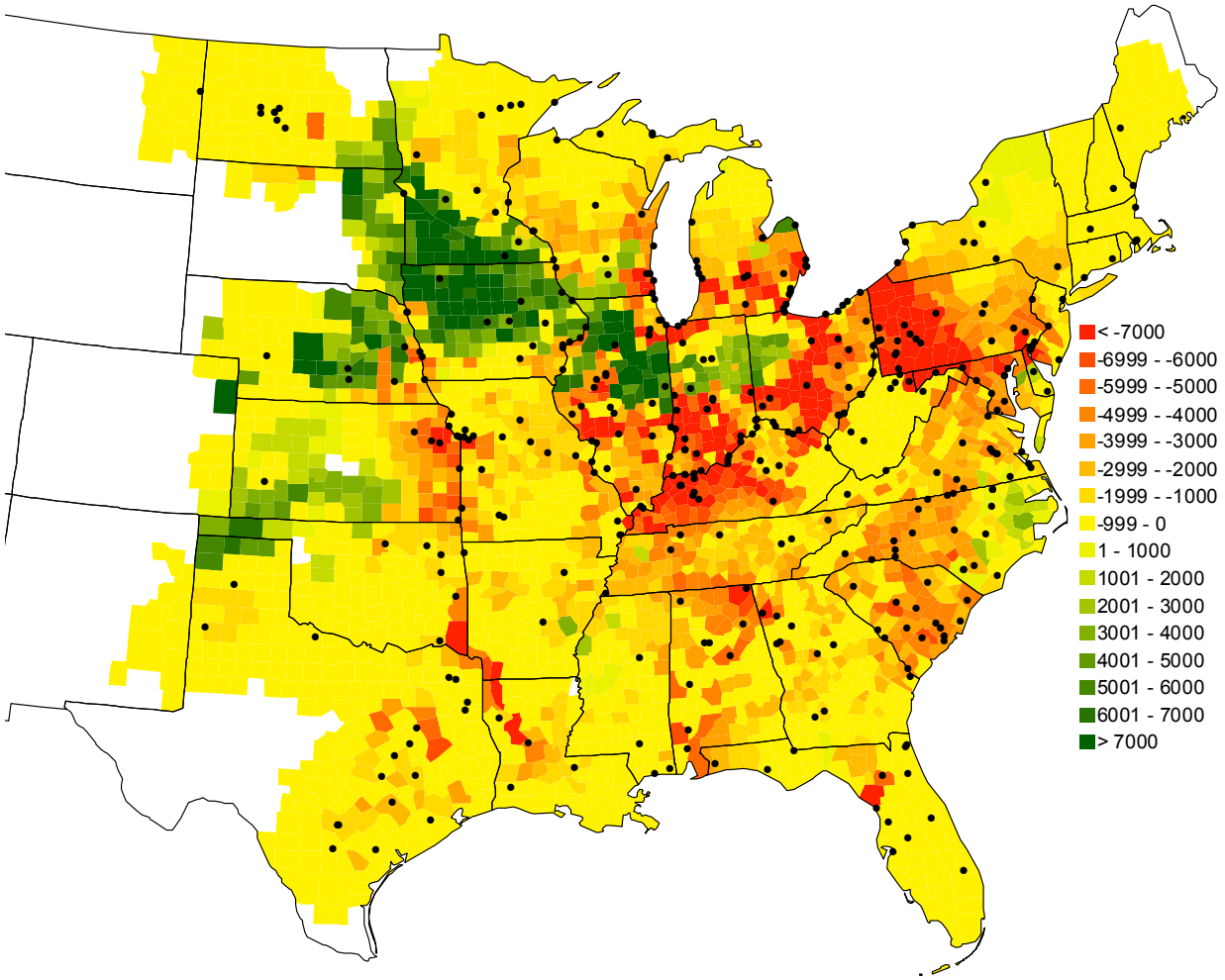


Figure : RPS = 15%, p_{bm} = \$4, Low Switchgrass Production Cost

RPS 25: Low Incentive



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RPS 25: High Incentive

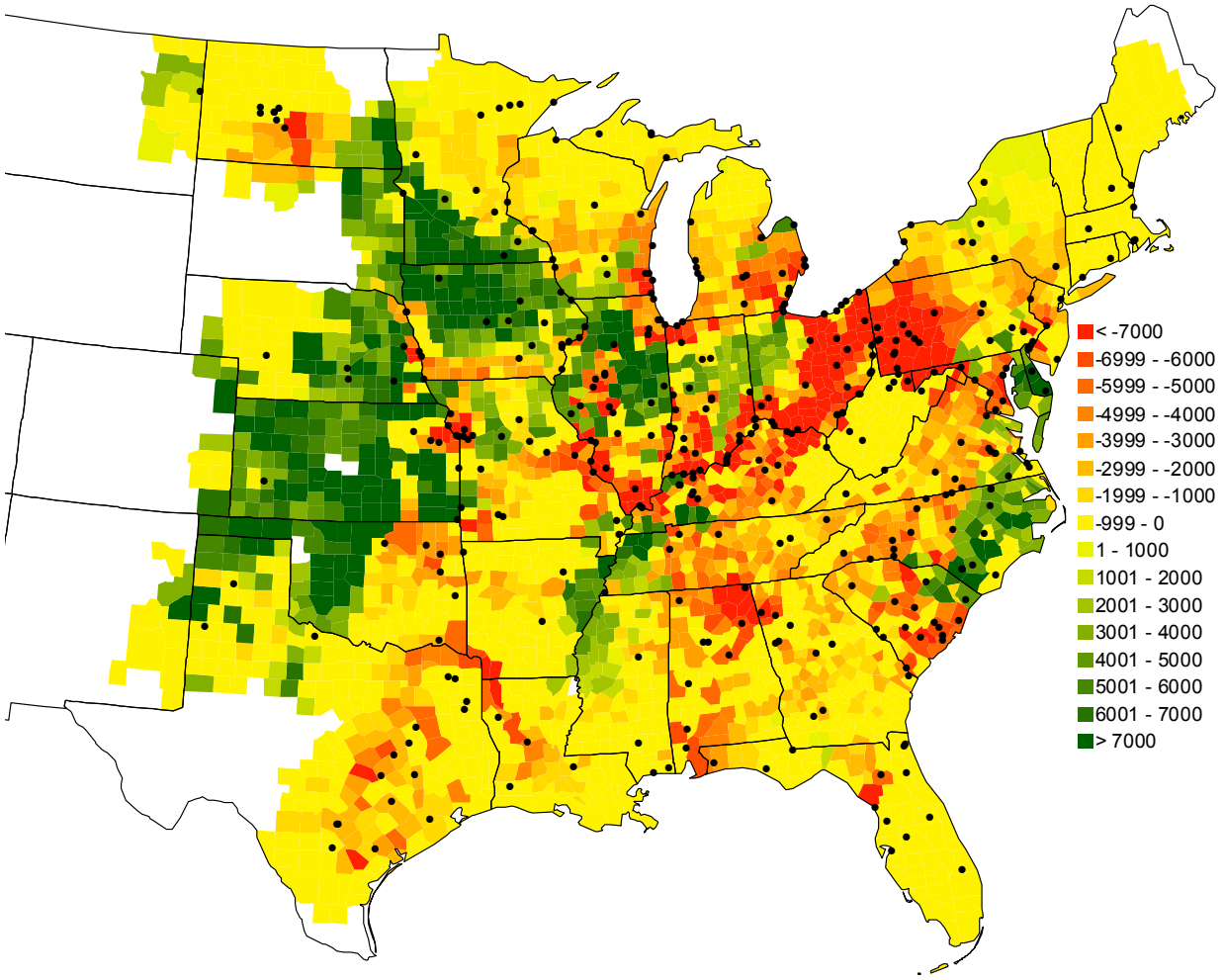

Figure : RPS = 25%, p_{bm} = \$4, Low Switchgrass Production Cost

Conclusion

Political perspective

- Legislation leading to the potential use of biomass for co-firing purposes due to state renewable portfolio standards

Coal-fired power plant perspective

- Possibility to mitigate greenhouse gas emissions by co-firing with biomass

Agricultural sector

- Possibility of additional revenue from selling to the power plant

Competition of power plants for limited supply of biomass